International Journal of Agriculture System
Vol. 9 Issue 2, December 2021
Nationally Accredited Journal Decree No. 48a/E/KPT/2017
P-ISSN: 2337-9782, E-ISSN: 2580-6815. DOI: 10.20956/ijas.v9i2.3164

Agricultural Land Evaluation Using GIS-Based Matching Method in Highland Areas for Oil Palm Cultivation

Muhammad Rendana[1*], Sahibin Abdul Rahim[2], Wan Mohd Razi Idris[3], Zulfahmi Ali Rahman[3], Tukimat Lihan[3]

[1] *Department of Chemical Engineering, Faculty of Engineering, Universitas Sriwijaya, Indralaya 30662 Sumatera Selatan, Indonesia.*
[2] *Department of Environmental Science, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400 Kota Kinabalu, Sabah, Malaysia.*
[3] *Department of Environmental Science, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.*

Corresponding author's e-mail: muhrendana@ft.unsri.ac.id

How to Cite: Rendana, M., Rahim, S.A., Idris, W.M.R, Rahman, Z.A., Lihan, T. (2021). Agricultural Land Evaluation Using GIS-Based Matching Method in Highland Areas for Oil Palm Cultivation. *Int. J. Agr. Syst. 9*(2): 103-115

ABSTRACT

Oil palm (Elaeis guineensis) is one of the commodity crops and mostly found in tropical lands. This study aimed to analyze the current and potential land suitability for oil palm using the geographic information system (GIS) technique. The study was conducted in the Ranau area, State of Sabah, Malaysia. Field activity was carried out to collect soil samples and land information in the study area. Land suitability was then assessed using the matching method and GIS software was employed to produce a land suitability map for oil palm. The results indicated that the current land suitability classes in the study area were highly suitable (S1) with a total area of 99,118 ha (27.4%), moderately suitable (S2) with 110,108 ha (30.4%), marginally suitable (S3) with 109,533 ha (30.2%), currently not suitable (N1) with 2,728 ha (0.7%), and permanently not suitable (N2) with 40,693 ha (11.3%). While the potential land suitability classes showed highly suitable (S1) was 198,206 ha (54.7%), moderately suitable class (S2) was 123,281 ha (34%) and permanently not suitable (N2) was 40,693 ha (11.3%). Suitable areas that could be planted with oil palm included the gently sloping flank and the low gradient slope margin. Availability of nutrients and work capability were the dominant limiting factors in the study area. The output of this study recommends that the Ranau area had the potential for oil palm although it still needs land improvements for sustainable oil palm cultivation.

Keywords:
GIS; Land suitability; Limiting factors; Oil palm; Ranau

1. Introduction

Recently, the management of land use planning for agriculture or public sectors must be estimated quickly and efficiently. In another word, the development of land use projects should be firstly analyzed to avoid loss of money in the future. Therefore, land suitability or land evaluation is the best method in evaluating the potential of lands based on the analysis of their characteristics for specific use, especially for agricultural functions (Rahmawaty et al., 2020). The primary aim of the land evaluation is to determine suitable areas for particular land use by calculating physical, social, economic, and conservation of practice for sustainable land use (Karthikeyan et al., 2019). Generally, the land is a physical environment that consists of soil, climate, topography, water, and plant. Interaction among these environmental factors could affect the potential of land (Zhang et al., 2020). Furthermore, the land characteristic is very associated with land quality, for example, soil texture and organic matter could govern the availability of water in soil (Senes et al., 2020).

Land suitability can be measured by comparing the required land characteristics for specific land use. To analyze land suitability, the geographical information system (GIS) technique has been widely applied to evaluate land suitability in many studies (Maleki et al., 2017; Ostovari et al., 2019; Kome et al., 2020; Pilevar et al., 2020; Radočaj et al., 2020). Several benefits of this technique are the evaluation process can be conducted rapidly and the presentation of land suitability outputs as shown in the map of spatial distribution (Abdullahi & Pradhan, 2018; Hassan et al., 2017). Also, the GIS can be used for collecting, classifying, and overlaying values of land characteristics in the form of a raster map.

In Malaysia, the oil palm crop has contributed to the highest income for this country. At this moment, this country had more than five million hectares of the planted area of oil palm, and the government still makes an effort to increase the allocation of land for this commodity crop (Sahibin et al., 2019). Ranau area is one of areas in the country with low total of planted area which is around 1,849 hectares. It was lower than other areas like Kinabatangan with a total planted area of about 279,108.4 hectares (Department of Statistic of Malaysia, 2019). Based on the result of previous studies, the soil properties in the Ranau area are suitable for oil palm cultivation (Sahibin et al., 2020; Simon et al., 2017), but limited works are available for land suitability analysis in this area because it was highland regions. Therefore, in the present study, we aim to analyze current and potential land suitability for oil palm cultivation in Ranau area using the geographical information system technique. The output of this study can be adopted by the local authority to increase the total planted area in the Ranau district.

2. Materials and Methods

2.1 Study area

The Ranau area located in Latitudes 5˚ 30′- 6˚ 25′N and Longitudes 116˚ 30′- 117˚ 5′E with covering a total area of about 3,612.8 km^2 (Figure 1). The Ranau area is an administrative district in the Malaysian State of Sabah. It lies 108 km east of Kota Kinabalu as the main town. The Ranau area consisted of hilly geographical areas or highland regions and was known as the largest producer of highland vegetables in this state. According to the geological history, the lithological study area is formed by a sedimentary rock from the Crocker and Trusmadi Formations, and also there was an igneous rock intrusion from Mount of Kinabalu. The suitable temperature and soil of the Ranau area make it has been utilized by farmers to grow horticultural crops such as cabbage, lettuce, tomato, carrot, capsicum and etc. Strawberry is one of the famous fruits which been successfully planted in this area. Also, different species of flowers are cultivated in this area for commercial functions. However, other commodity crops such as oil palm are not optimally planted yet in the study area. Currently, the total area with oil palm cultivation in the study area is only around ±2,000 hectares, it was recorded lower than other areas within this region.

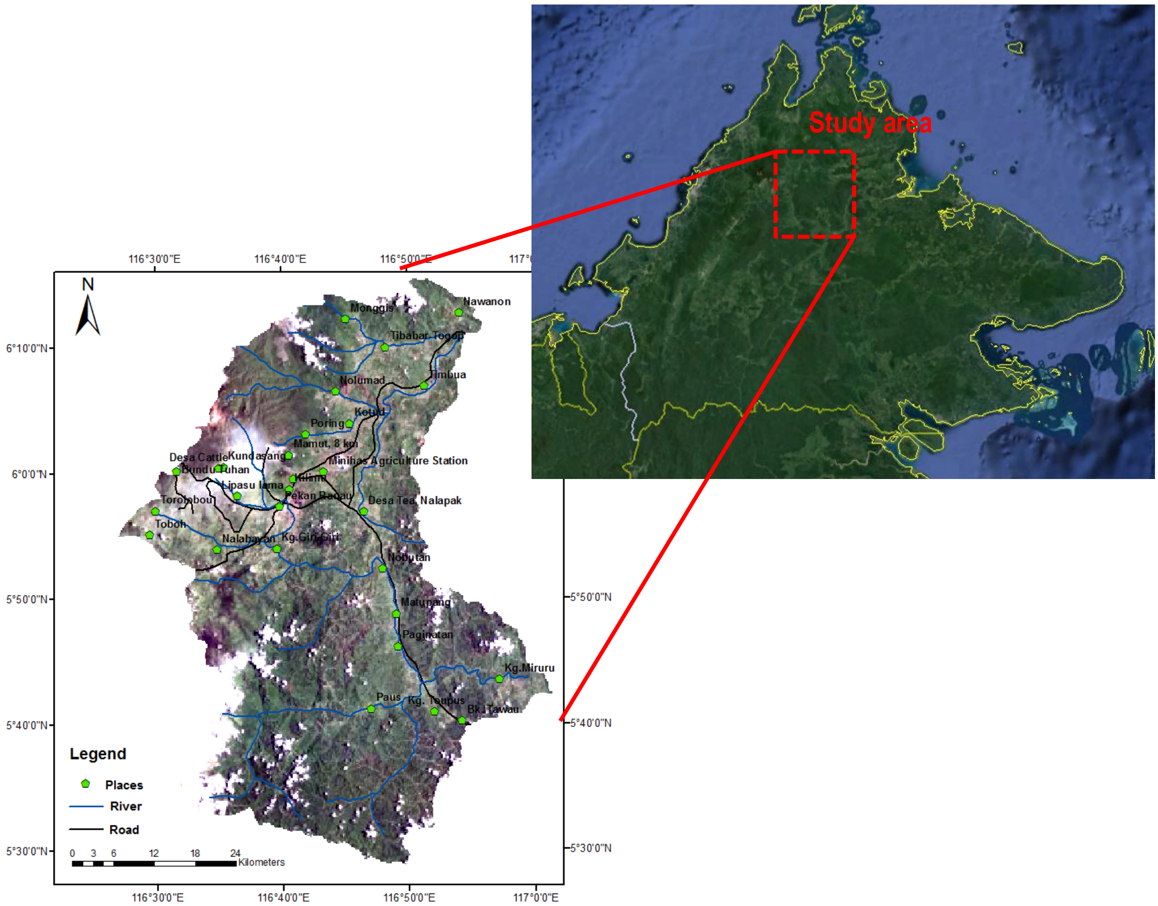

Figure 1. Location of the study area

2.2 Data collection

Data used in this study such as soil data, climate data, topographical data, and oil palm crop requirement data. Field activity was carried out to collect soil samples and land information using the GPS Garmin Etrex 10 device. There were about 100 sampling points were collected for this study. The soil samples were then brought to the laboratory for physical and chemical analysis such as pH, electrical conductivity, nutrient content, heavy metals, and soil texture. The oil palm requirement data was obtained from the previous study (Sahibin, 1995). Climate data were obtained from the meteorological stations in the study area. Furthermore, topographical data were extracted from Nasa's Shuttle Radar Topography Mission to generate the Digital Elevation Model (DEM) for the study area.

2.3 Data analysis

In this study, we used the matching technique to assess land suitability for oil palm. In general, land suitability analysis was conducted by matching the land characteristics (Table 1) with the crop requirements (Table 2). Leibig's low law was applied to analyze the limiting factors that governed the land suitability class (Ritung et al., 2011). This technique fitted the data from the laboratory and the field with the crop requirements. The land suitability analysis was divided into five main classes such as highly suitable

ISSN: 2337-9782, **E-ISSN:** 2580-6815

(S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and permanently not suitable (N2) (Food and Agriculture Organization, 1976). The spatial analysis technique was used to obtain the variation of land suitability classes in the study area, this technique interpolated mean values of each land characteristic (e.g. soil and climate parameters) based on-field activity, then the associated land characteristics were overlaid to produce a land quality map. The ArcGIS software version 10 was employed to map current land suitability for oil palm in the study area. For the potential land suitability map, we reclassified the S3 and N1 classes into the S2 class. This was because the current limiting factors in the S3 and N1 classes could still be improved to increase the land suitability index for oil palm cultivation.

Table 1. The association between land qualities and land characteristics

Land qualities	Land characteristics
Water availability	Rainfall, dry month duration, soil depth, soil texture
Oxygen availability	Drainage, flood event, soil texture, rainfall
Nutrient availability	pH, available-P, available-K, available-Mg, soil texture
Work capability	Stone mass percentage, slope, elevation, drainage
Toxicity	Electrical conductivity, heavy metals

Table 2. Level of land characteristics and land qualities for oil palm cultivation

Land characteristics/ Land Qualities	Level of limiting factors and land suitability classes				
	None	Slight	Moderate	Poor	Very poor
	S1	S2	S3	N1	N2
Water availability					
Rainfall (mm/year)	>2000	2000-1500	1500-1250	-	<1250
Dry month (month)	<2	2-3	3-4	-	>4
Soil texture	SSiL, SiL	SCL, C	LS	-	S
Drainage	Very good	Good	Medium	Poor	Very Poor
Soil depth (cm)	>100	100-50	50-20	20-10	<10
Nutrient availability (mg/kg)					
Available K	>312.8	156.4-312.8	78.2-156.3	<78.2	-
Available Mg	>54	36-54	18-35	<18	-
pH	5.6-7.0	7.1-8.0	4.5-5.5	<4.0, >8.0	-
Available P	>25	15-25	6-14	<6	-
Oxygen availability					
Soil texture	SSiL, SiL	SCL, C	LS	-	S
Flood event	None	Rarely	Occasionally	-	Frequently
Drainage	Very good	Good	Medium	Poor	Very Poor
Work capability					
Stone mass (%)	0-15	16-30	31-55	-	>55
Slope (°)	0-6	6-12	12-25	-	>25
Toxicity(mg/kg)					
Cd	0-1	1-3	3-8	-	>8
Cr	0-50	50-75	75-100	-	>100
Cu	0-30	30-60	60-125	-	>125
Ni	0-15	15-25	25-50	-	>50
Pb	0-50	50-100	100-250	-	>250
Zn	0-80	80-150	150-300	-	>300
Electrical conductivity (mS/cm)	0-4	4-8	8-15	-	>15

The spatial analysis technique was used to obtain the variation of land suitability classes in the study area, this technique interpolated mean values of each land characteristic (e.g., soil and climate parameters) based on-field activity, then the associated land characteristics were overlaid to produce a land quality map. The ArcGIS software version 10 was employed to map current land suitability for oil palm in the study area. For the potential land suitability map, we reclassified the S3 and N1 classes into the S2 class. This was because the current limiting factors in the S3 and N1 classes could still be improved to increase the land suitability index for oil palm cultivation.

3. Results and Discussion

3.1 Spatial distribution map of land quality

The land suitability assessment could be used as a fundamental way for arranging land use planning and decision-making. Recently, the GIS method has been widely applied to analyze land suitability in many studies (Nurda et al., 2020; Radočaj et al., 2020). One of the best benefits of applying GIS was the assessment and the presentation of its outputs could be done in spatial maps to describe the distribution of certain geographic objects (Habibie et al., 2019; Nguyen et al., 2020). The GIS was also used for data repository, data management, and data analysis of all geographic objects. There were many studies that elaborated the evaluation of land suitability on conventional agriculture, farming, and commodities crop, but limited studies were found for the oil palm cultivated in highland areas. Because the land capacity for oil palm cultivation would reduce year after year while the global demand for oil palm was still high. Thus, the expansion of the use of agricultural land including marginal areas like highland areas had the important key for escalating the total planted area.

Figure 2 showed a spatial distribution map of land quality in the study area such as water availability, nutrient availability, oxygen availability, work capability, and toxicity. The spatial map of water availability indicated about 336,542 ha (93%) was classified at moderately suitable (S2), and 5,773 ha (1.5%) was marginally suitable (S3) (Figure 2a). While 19,865 ha (5.5%) was classified as permanently not suitable (N2), this area included Mount of Kinabalu with a high mass of stone, shallow soil depth which made the soil in this area did not have water storage for agricultural purposes. Therefore, limiting factors that affected land suitability classes S2 and S3 were soil texture, soil drainage, and rainfall distribution. Water availability was a prominent land quality for oil palm because it was an interaction between climate and soil parameters. The oil palms usually needed water in much quantity for their growth. Waite et al. (2019) revealed soil water availability would affect palm height on the anatomy of oil palm fronds. But, according to our result, we assumed that the study area could be cultivated by oil palm because almost 90% of the area had good water availability in soil. In addition, the annual rainfall of the study area was more than 2,000 mm thus it could provide water availability for the crop, especially in the area with soil depth was more than 50 cm. This notion was consistent with other studies that assumed the optimum value of annual rainfall for oil palm growth ranged from 2,000 – 3,500 mm and the dry month period was not more than two months (Rahmawaty et al., 2020). Rainfall would affect the number of fruits, the bunch weight, and the oil palm production (Gunawan et al., 2020).

Nutrient availability generally referred to the availability of macronutrients such as potassium, magnesium, and phosphorus in soil. Generally, the nutrient deficiency in soil could be improved using standard fertilization. The nutrient content in the study area was found at a low level. It might due to soil erosion and leaching processes that frequently occurred in this area. Our result found about 339,587 ha (93.8%) was classified as marginally suitable (S3) for oil palm, while 2,728 ha (0.7%) was permanently not suitable (N2) (Figure 2b). Limiting factors that affected land suitability classes S3 and N1 were pH value and the contents of phosphorus (P), potassium (K), and magnesium (Mg) in the soil. The lowest content of macronutrients was observed at N1 class, this area consisted of the ex-mining area (Mamut copper mine). There were two reasons for the low content of nutrient in that area, firstly, the area has been exposed to the environmental condition that attributed to nutrients tended to easily lose through leaching and erosion processes. Secondly, the soil pH in the ex-mining area was acidic (pH 4.0 – 5.5) that could lead to a high solubility process of macronutrients. Meanwhile, other studies assumed soil texture had a main role in controlling nutrient leaching losses, nutrient stocks, soil fertility, and nutrient cycling in the weathered soils (Kurniawan et al., 2018).

The spatial map of oxygen availability showed around 180,810 ha (50%) was classified at moderately suitable (S2), while 161,505 ha (45%) at marginally suitable (S3) (Figure 2c). Limiting factors that affected land suitability classes S2 and S3 were drainage and texture of the soil. The combination of soil texture, flood events, and drainage factors would determine the status of oxygen availability in soil for plant growth. Furthermore, Oktarita et al. (2017) assumed soil water and the water-filled pore space were a benchmark of oxygen availability in soil. In the Southeast Asian region, the oxygen availability in soil was quite good, it was shown in a study by Harahap et al. (2019) that found the availability of oxygen in Pakpak Bharat District of North Sumatera, Indonesia was at a good level for oil palm cultivation. This result was consistent with our study that obtained more than 80% of the study area classified as a suitable condition for oil palm. In general, the oil palm needed at least 30% of aeration in the soil to supply good oxygen availability for the crop. Flood-prone areas that did not have good drainage would cause increased soil saturation and decrease the status of aeration in the soil. The best areas for oil palm cultivation based on this study were characterized with moderate drainage, moderate soil texture, and not flood-prone areas.

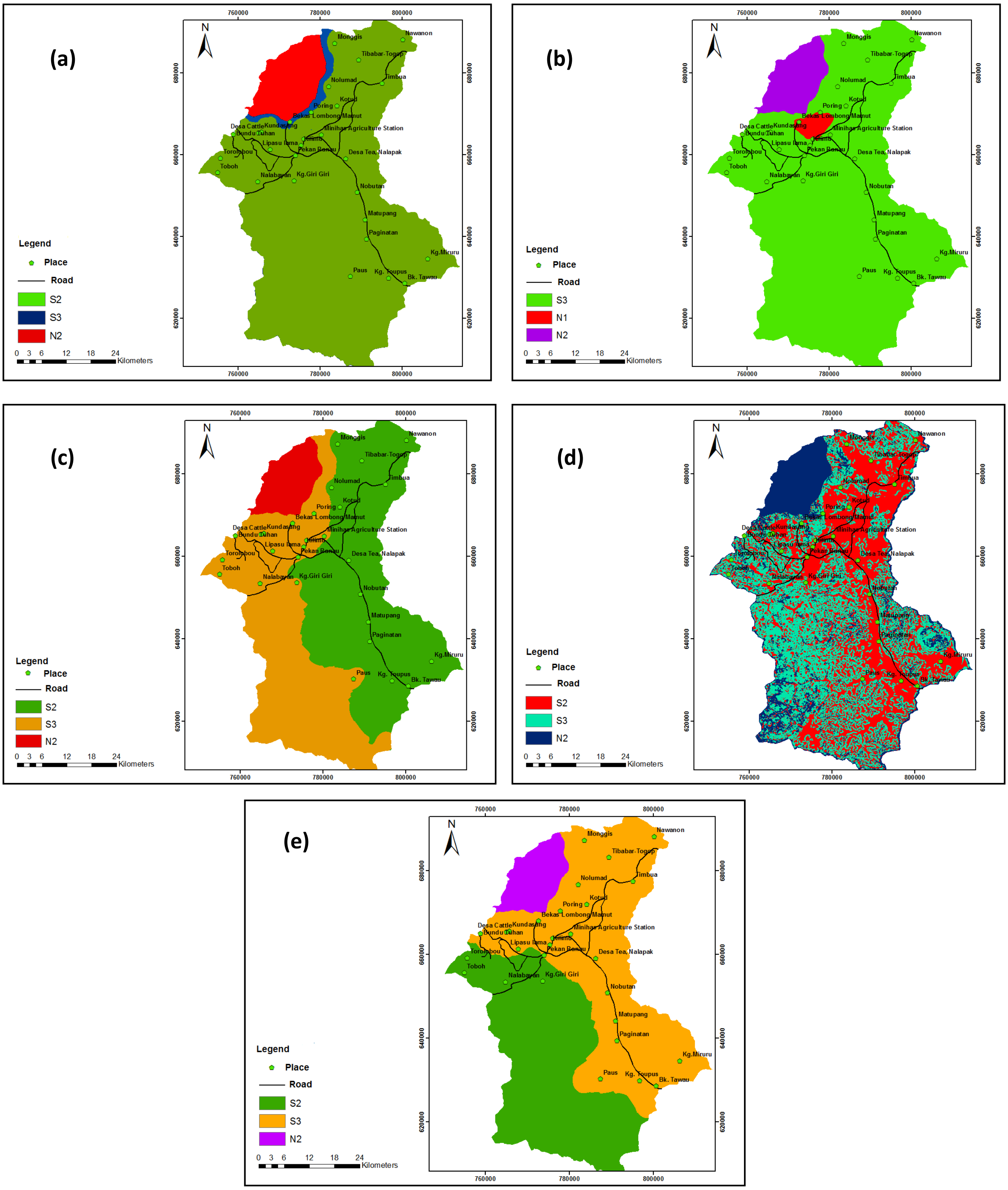

Figure 2. Map of land qualities for oil palm cultivation in the study area, (a) water availability, (b) nutrient availability, (c) oxygen availability, (d) work capability, and (e) toxicity

The spatial map of work capability showed 147,123 ha (41.1%) was classified at moderately suitable (S2), 171,364 ha (47.6%) was marginally suitable (S3) and 40,693 ha (11.3%) was permanently not suitable (N2) (Figure 2d). Dominant limiting factors that contributed to the S2 and S3 classes were the degree of steepness and soil texture in the study area. While, the N2 class was indicated with limiting factors such as degree of steepness, stone mass, and soil depth. The work capability was occasionally related to the capability of excavation machines was employed in a certain area. The degree of difficulties of land preparation was affected by stone mass, slope, and elevation of the proposed lands. For instance, the oil palm planted in the steep area would make it the workers became difficult to pick fruits. Therefore, Abd Aziz et al. (2019) assumed the degrees of steepness for oil palm cultivation should not more than 25˚ for the plan table areas. Moreover, the spatial map of toxicity indicated about 158,278 ha (43.7%) was classified as moderately suitable (S2), while 184,037 ha (50.8%) was marginally suitable (S3) (Figure 2e). The limiting factors that contributed to the S2 and S3 classes in the study area were high concentrations of nickel (Ni), copper (Cu), and chromium (Cr) in the soil. The presence of heavy metals in soil could significantly decrease soil fertility for crop growth. A study by Tashakor et al. (2018) found high content of Cu (1,650 μg/L) and Zn (134 μg/L) in the adjacent rivers from the ex-mining site. Van der Ent and Edraki (2018) assumed the primary source of the heavy metal pollution in the rivers was derived from the Mamut copper mine and Cu-rich acid mine drainage that drained from the sites near the area.

3.2 Current land suitability for oil palm

The result of overlay analysis for all land qualities has produced the current land suitability map for oil palm in the study area. Table 3 showed about 99,118 ha (27.4%) of the study area was classified as highly suitable (S1), 110,108 ha (30.4%) was moderately suitable (S2), 109,533 ha (30.2%) was marginally suitable (S3), 2,728 ha (0.7%) was at currently not suitable (N1) and 40,693 ha (11.3%) was at permanently not suitable (N2). Some areas with highly suitable classes for oil palm cultivation were showed at the northeast and the east then to the southeast parts of the study area (Figure 3). These areas were found at the lower elevation and gentle slope areas. In contrast, currently not suitable areas were mostly found in the ex-mining area and its surroundings. This area was categorized into the N1 class because it had a limiting factor such as nutrient availability problem. While permanently not suitable areas consisted of hilly areas with the steepness value was more than 25˚. Dominant limiting factors in this class were work capability which included steepness and elevation factors. These areas also covered reserved forest areas which could not be developed for any human activities in the northwest and the southwest parts of the study area.

Table 3. The current and potential land suitability classes for oil palm in the study area

Land suitability analysis	Suitability classes	Limiting factors	Area	
			Ha	%
Current land suitability	S1	-	99,118	27.4
	S2	na,to,oa,wc,wa	110,108	30.4
	S3	na,to,oa,wa,wc	109,533	30.2
	N1	na	2,728	0.7
	N2	wc	40,693	11.3
Potential land suitability	S1	-	198,206	54.7
	S2	-	123,281	34
	N2	wc	40,693	11.3

Note: na: nutrient availability, to: toxicity, oa: oxygen availability, wa: water availability, wc: work capability.

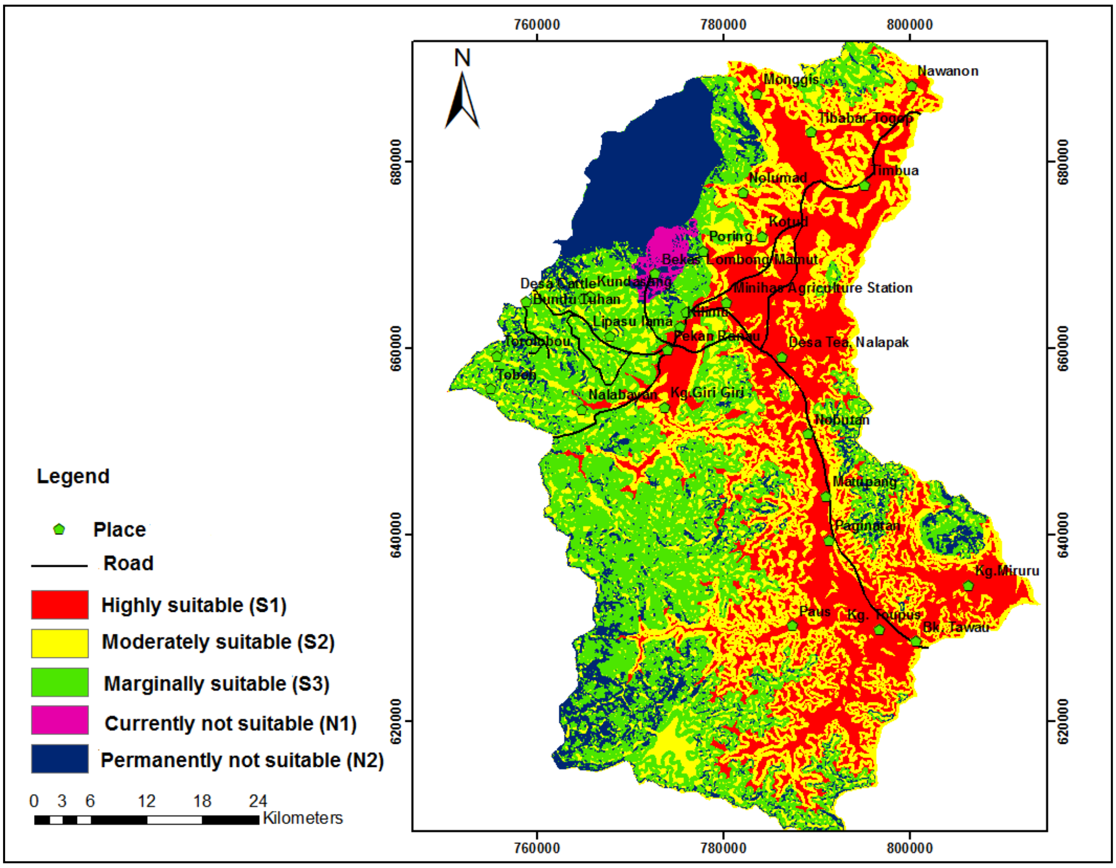

Figure 3. Map of current land suitability for oil palm cultivation in the study area

3.3 Potential land suitability for oil palm

Potential land suitability analysis was calculated by considering all limiting factors in the marginally suitable and currently not suitable classes have been improved thus they were suitable for oil palm cultivation. For example, the nutrient deficiency was improved using standard fertilization technique, low pH with liming, poor drainage, and aeration with organic amendment application. However, for other permanent limiting factors such as work capability which consisted of high mass of stone, steepness, and elevation, it could not be improved due to high cost, thus the area under this condition still remained in the N2 class. Figure 4 showed a potential land suitability map for oil palm cultivation. There was an increase of S1 and S2 classes after improving land characteristics in the current land suitability map.

As a whole, our results for potential land suitability analysis revealed that the highly suitable class (S1) was about 198,206 ha (54.7%), moderately suitable class was 123,281 ha (34%), while for permanently not suitable was around 40,693 ha (11.3%) (Table 3). Our study suggested the assessment and selection of optimal land for oil palm could be determined by using a GIS-based matching method where the highest land characteristics and the least limiting factors were found. Then, land policy administrators could improve oil palm quality and decrease the plantation expense.

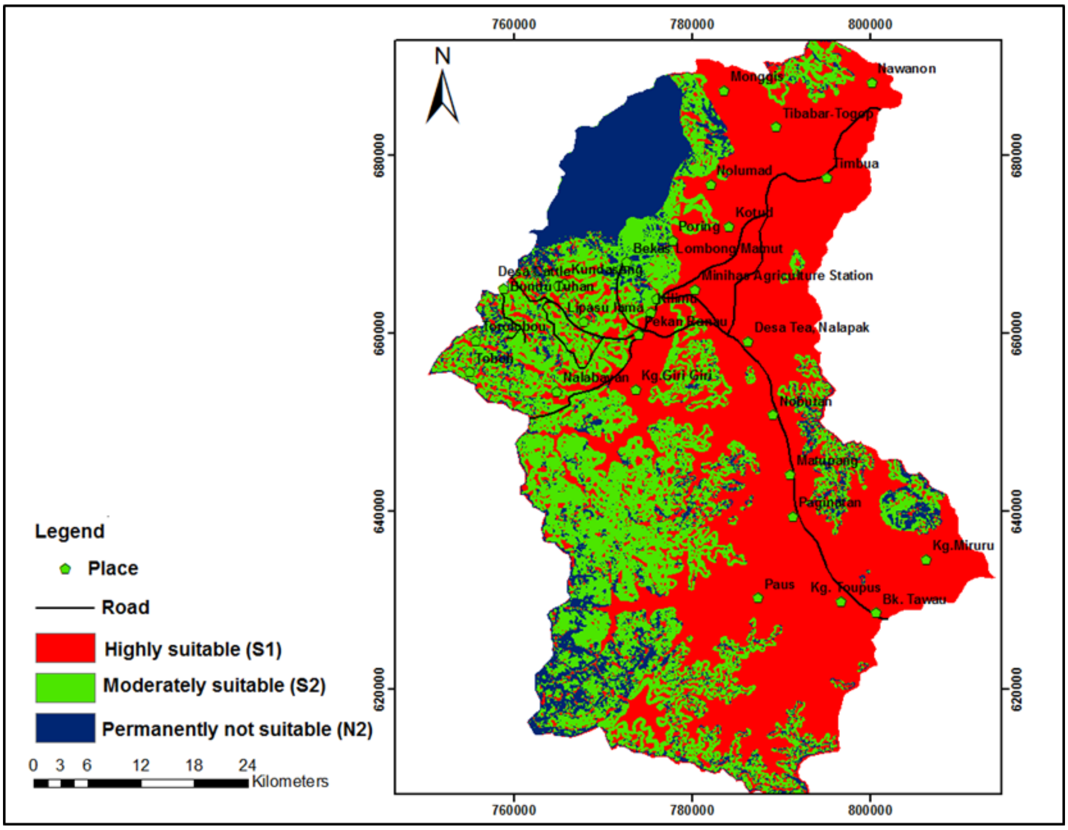

Figure 4. Map of potential land suitability for oil palm cultivation in the study area

4. Conclusion

This study revealed that the total area of suitable classes in the current land suitability map was around 209,226 ha, but after all land qualities have been improved, we estimated the total area of suitable class increased to 321,487 ha. Hence, our result concluded that the study area was found very suitable for oil palm cultivation, with highly suitable (54.7%) and moderately suitable (34%). The output of this study can be used for the local authority to determine where the suitable areas for oil palm thus the utilization of land can be carried out at maximum capacity. Therefore, it was expected to increase oil palm production in the study area. While, for other not suitable areas (11.3%) can be utilized for the reserved forests, recreational and national parks.

Acknowledgements

The authors would like to thank the National University of Malaysia for providing research grants No. FRGS/2/2013/STWN01/UKM/01/2 and UKM-GUP-2011-182. Soil analysis was carried out at the soil laboratory, while spatial analysis at the Remote sensing and GIS laboratory, Faculty of Science and Technology, the National University of Malaysia.

References

Abd Aziz, N., Omar, W., Samah, M. and Hashim, Z. (2019). Topographic Information from Interferometric Synthetic Aperture Radar (IfSAR) for Oil Palm Plantation Design, Suitability and Management. Journal of Environmental Science and Engineering, 8: 159-172.

Abd Rahim, S., John, I. J., Hamdan, D. D. M., Zahari, N. Z. and Musta, B. (2020). Physico-Chemical Properties of Ultrabasic Soil from Mibang, Ranau, Sabah. Transactions on Science and Technology, 7(4): 219–224.

Abdullahi, S. and Pradhan, B. (2018). Land use change modeling and the effect of compact city paradigms: integration of GIS-based cellular automata and weights-of-evidence techniques. Environmental earth sciences, 77(6): 1-15.

Department of Statistic of Malaysia. (2019). Census Report of Malaysian Agricultural Organizations. Department of Statistic of Malaysia.

Food and Agriculture Organization. (1976). Framework for land evaluation. FAO.

Gunawan, S., Budiastuti, M. T. S., Sutrisno, J. and Wirianata, H. (2020). Effects of organic materials and rainfall intensity on the productivity of oil palm grown under sandy soil condition. International Journal on Advanced Science, Engineering and Information Technology, 1: 6-3.

Habibie, M. I., Noguchi, R., Shusuke, M. and Ahamed, T. (2019). Land suitability analysis for maize production in Indonesia using satellite remote sensing and GIS-based multicriteria decision support system. GeoJournal, 1-31.

Harahap, F. S., Sitompul, R., Rauf, A., Harahap, D. E. and Walida, H. (2019). Land suitability evaluation for oil palm plantations (Elaeisguenensis jacq) on Sitellu Tali Urang Julu, Pakpak Bharat District. IOP Conference Series: Earth and Environmental Science, 260(1): 1-8.

Hassan, F. O., Salam, A. A. A., Rashed, H. S. and Faid, A. M. (2017). Land evaluation and suitability of Hala'ib and Shalateen region, Egypt, by integrated use of GIS and remote sensing techniques. Annals of Agricultural Science, Moshtohor, 55: 151-162.

Karthikeyan, K., Kumar, N., Yousuf, A., Bhople, B. S. and Naitam, R. K. (2019). Land Evaluation: A General Perspective. CRC Press.

Kome, G. K., Tabi, F. O., Enang, R. K. and Silatsa, F. B. T. (2020). Land Suitability Evaluation for Oil Palm (Elaeis guineensis Jacq.) in Coastal Plains of Southwest Cameroon. Open Journal of Soil Science, 10(07): 257.

Kurniawan, S., Corre, M. D., Matson, A. L., Schulte-Bisping, H., Utami, S. R., Straaten, O. V. and Veldkamp, E. (2018). Conversion Of Tropical Forests to Smallholder Rubber and Oil Palm Plantations Impacts Nutrient Leaching Losses and Nutrient Retention Efficiency in Highly Weathered Soils. Biogeosciences, 15(16): 5131-5154.

Maleki, F., Kazemi, H., Siahmarguee, A. and Kamkar, B. (2017). Development of A Land Use Suitability Model for Saffron (Crocus sativus L.) Cultivation by Multi-Criteria Evaluation and Spatial Analysis. Ecological Engineering, 106: 140-153.

Nguyen, H., Nguyen, T., Hoang, N., Bui, D., Vu, H. and Van, T. (2020). The Application of LSE Software: A New Approach for Land Suitability Evaluation in Agriculture. Computers and Electronics in Agriculture, 173: 1-8.

Nurda, N., Noguchi, R. and Ahamed, T. (2020). Change Detection and Land Suitability Analysis for Extension of Potential Forest Areas in Indonesia Using Satellite Remote Sensing and GIS. Forests, 11(4): 398.

Oktarita, S., Hergoualc'h, K., Anwar, S. and Verchot, L. V. (2017). Substantial N2O Emissions from Peat Decomposition and N Fertilization in an Oil Palm Plantation Exacerbated By Hotspots. Environmental Research Letters, 12(10): 1-8.

Ostovari, Y., Honarbakhsh, A., Sangoony, H., Zolfaghari, F., Maleki, K. and Ingram, B. (2019). GIS and Multi-Criteria Decision-Making Analysis Assessment of Land Suitability for Rapeseed Farming in Calcareous Soils Of Semi-Arid Regions. Ecological Indicators, 103: 479-487.

Pilevar, A. R., Matinfar, H. R., Sohrabi, A. and Sarmadian, F. (2020). Integrated Fuzzy, AHP and GIS Techniques for Land Suitability Assessment In Semi-Arid Regions for Wheat and Maize Farming. Ecological Indicators, 110: 105887.

Radočaj, D., Jurišić, M., Gašparović, M. and Plaščak, I. (2020). Optimal Soybean (Glycine max L.) Land Suitability Using Gis-Based Multicriteria Analysis and Sentinel-2 Multitemporal Images. Remote Sensing, 12(9): 1463.

Rahmawaty, R., Frastika, S., Rauf, A., Batubara, R. and Harahap, F. S. (2020). Land Suitability Assessment for Lansium Domesticum Cultivation on Agroforestry Land Using Matching Method and Geographic Information System. Biodiversitas Journal of Biological Diversity, 21(8): 1-8.

Ritung, S., Nugroho, K., Mulyani, A. and Suryani, E. (2011). Technical Guidelines for Evaluating Land for Agricultural Commodities (Revised edition). Center for Agricultural Land Resources Research and Development, Agricultural Research and Development Center, Bogor.

Sahibin, A. R. (1995). System of Crop Selection in Relation to Land Suitability in the Ranau District Sabah, Malaysia [Unpublished Doctoral dissertation]. University of Wales.

Sahibin, A.R., Shamshuddin, J., Fauziah, C.I., Radziah, O., Wan Mohd Razi, I. and Enio, M.S.K. (2019). Impact of Mg Rich Synthetic Gypsum Application on The Environment and Palm Oil Quality. Science of the Total Environment, 652: 573–582.

Senes, G., Fumagalli, N., Ferrario, P. S., Rovelli, R. and Sigon, R. (2020). Definition of a Land Quality Index to Preserve the Best Territories From Future Land Take. An application to a study area in Lombardy (Italy). Journal of Agricultural Engineering, 51(1): 43-55.

Simon, N., Azlan, N. N. N., Roslee, R., Hussein, A., Ern, L. K. and Sharir, K. (2017). Physical Soil Characterization on Stable and Failed Slopes of the Ranau-Tambunan Road, Sabah, Malaysia. Nature Environment and Pollution Technology, 16(2): 659.

Tashakor, M., Modabberi, S., Van der Ent, A. and Echevarria, G. (2018). Impacts of Ultramafic Outcrops in Peninsular Malaysia and Sabah on Soil And Water Quality. Environmental monitoring and assessment, 190(6): 1-19.

Van der Ent, A. and Edraki, M. (2018). Environmental Geochemistry Of The Abandoned Mamut Copper Mine (Sabah) Malaysia. Environmental Geochemistry and Health, 40(1): 189-207.

Waite, P. A., Schuldt, B., Mathias Link, R., Breidenbach, N., Triadiati, T., Hennings, N. and Leuschner, C. (2019). Soil Moisture Regime and Palm Height Influence Embolism Resistance in Oil Palm. Tree physiology, 39(10): 1696-1712.

Zhang, X., Du, S., Du, S. and Liu, B. (2020). How Do Land-Use Patterns Influence Residential Environment Quality? A Multiscale Geographic Survey in Beijing. Remote Sensing of Environment, 249: 112014.